LHeC: Motivation, Design(s), Prospects, Plans

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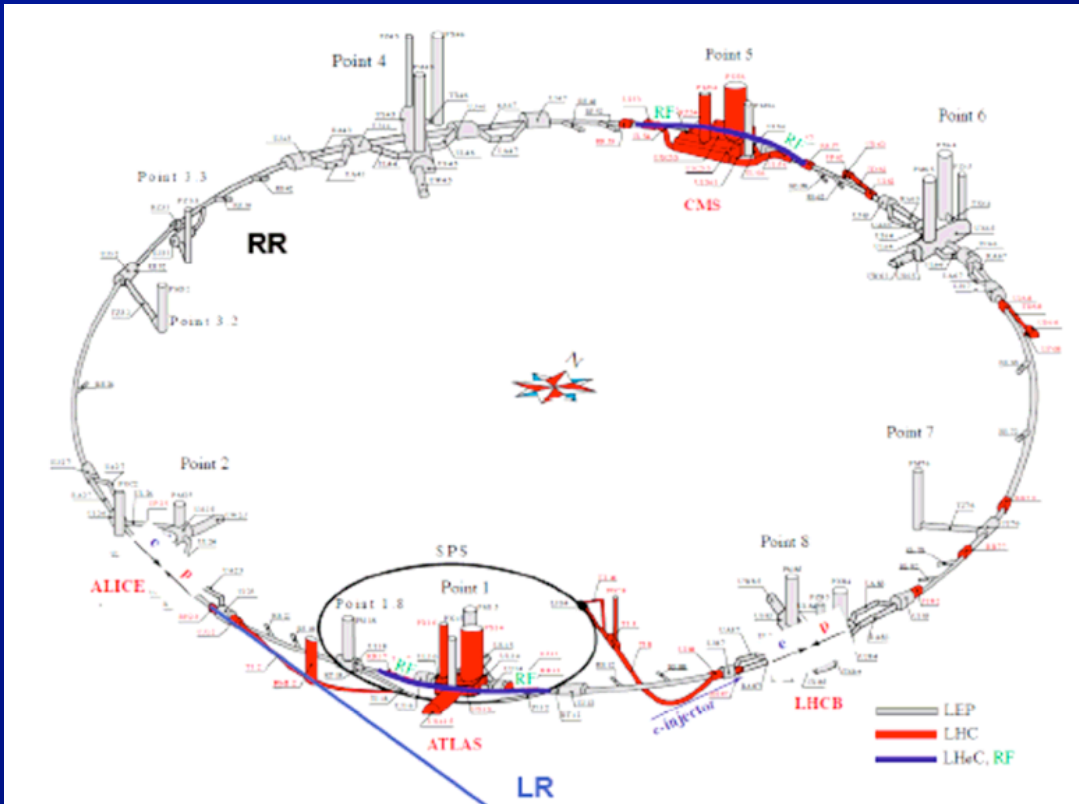


Caveat Emptor:

I am NOT an expert. My (limited) role in LHeC is that I am co-convener of e-A physics WG.

The LHeC

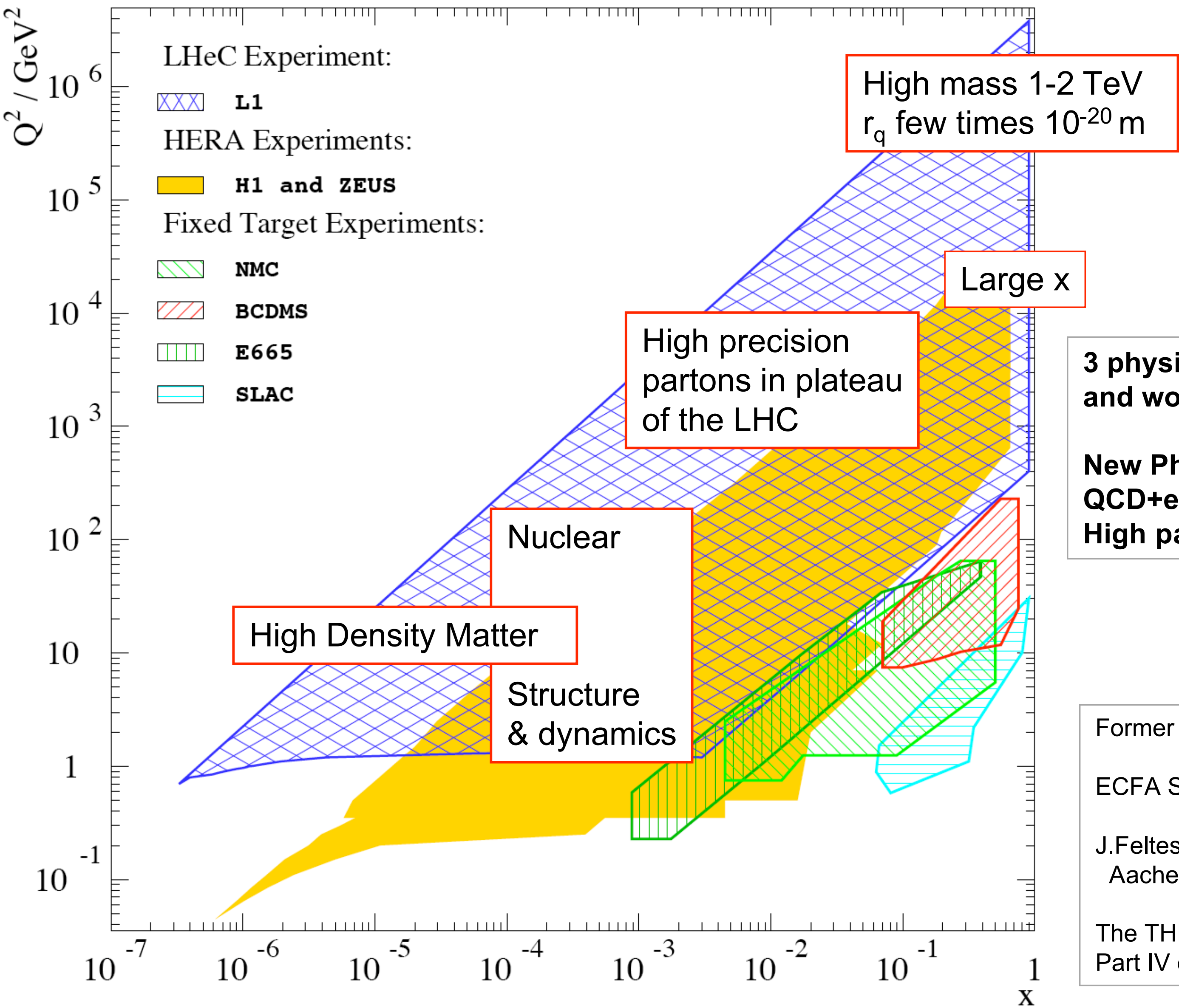
$e^{\pm} + p$, $e^{\pm} + A$ collider using LHC

- electron energies from 20-140 GeV
  - But a possible staging option using SPL

    ⇒electron energies from 5-20 GeV
- p from 1-7 TeV
- A as large as Pb from 0.4 - 2.8 TeV
- Electron acceleration by
  - Additional ring in LHC tunnel (RR)
  - Addition of LINAC (LR)

    ⇒ Relation to CLIC?

LHeC “Reach”



3 physics subjects and working groups:

New Physics
QCD+electroweak
High parton densities

Former considerations:

ECFA Study 84-10

J.Feltesse, R.Rueckl:
Aachen Workshop (1990)

The THERA Book (2001)&
Part IV of TESLA TDR

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LHeC Physics

- **Beyond SM physics, partial list:**
  - SUSY
  - Lepto-quarks
  - Excited leptons, lepton structure
  - quark structure, …
    - ⇒Physics for which LHC has discovery potential but which is difficult to resolve
- **Precision SM physics, partial list:**
  - Higgs w/ cleaner final states
  - t-tbar and stop production
  - Precision α_s measurements

LHeC Physics (II)

- **Precision nucleon structure**
  - u/d and g(x) for x→1
  - Intrinsic heavy flavor (up to t ?)
  - Valence quark distributions from γ-Z interference ($xF_3^{\gamma Z}$)
  - s(x) from charged-current interactions
- **Low x physics**
  - Evolution at low x (BFKL vs RS DGLAP)
  - Nucleon, nuclear DIS: F_2, F_L, …
  - Hard diffraction in e-p, e-A
  - Saturation, QCD in unitarity limit

Machine: Physics Requirements

- M. Klein from Nov 08 report to ECFA

Machine Requirements

-New physics expected at TeV scale. Low $x=Q^2/sy$, $s=4E_eE_p$

highest possible E_e and E_p **1 TeV with 50 GeV on 5000 GeV**

-New physics is rare [σ_{ep} (Higgs) = O(100)fb] , rate at high Q^2 , large x

L has to exceed 10^{32} and preferentially reaches 10^{33} and beyond

-New states, DVCS, electroweak physics

Need electrons and positrons and lepton beam polarisation

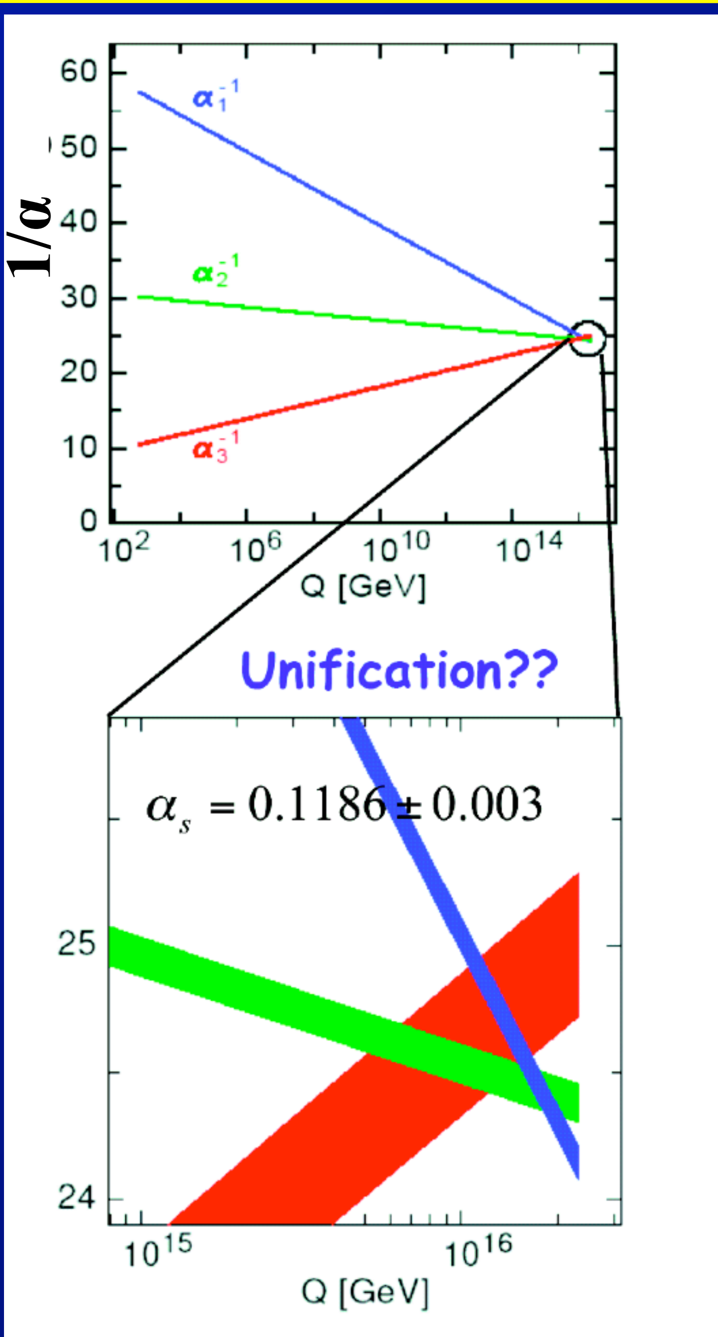
-Neutron structure terra incognita

Deuterons

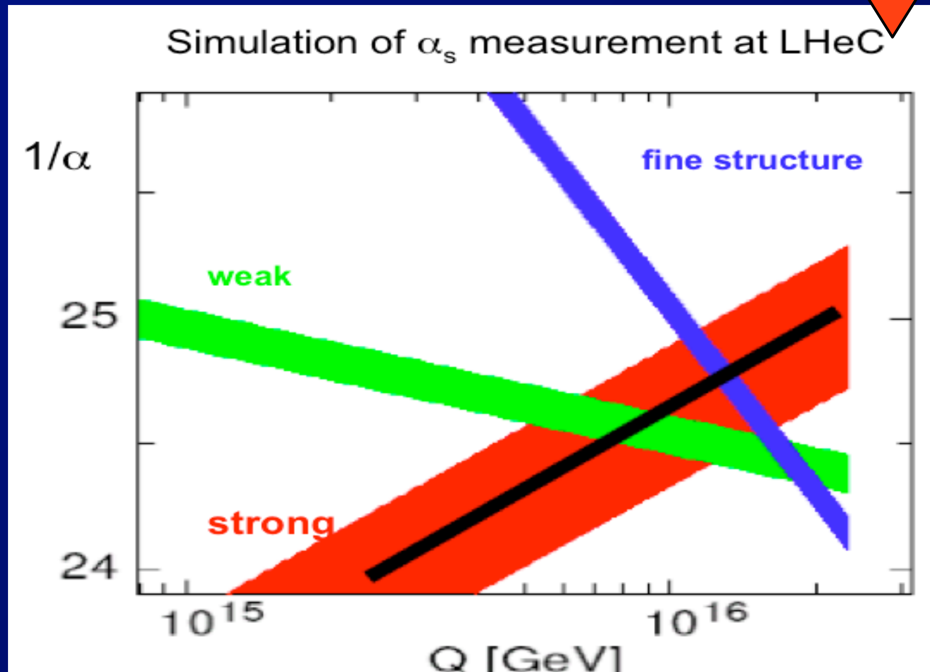
-Partonic Structure of Nuclei

a series of nuclei, Ca, Pb

Precision α_s Measurement



DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

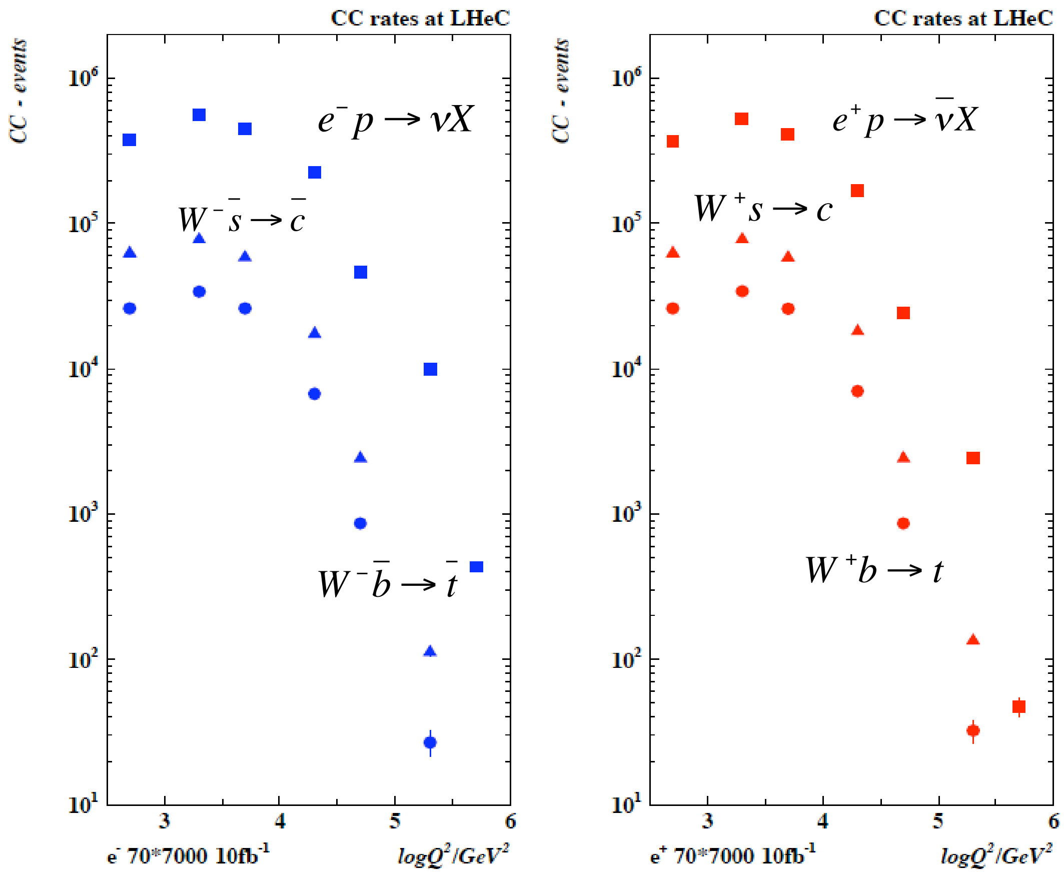


Charged Current Measurements

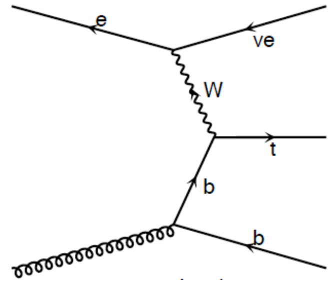
u
d
u_v
d_v
ubar
dbar
s
sbar
c/cbar
b/bbar
t
tbar
xg

with
NC,CC
$e^{\pm}p, e^{\pm}D$

Single (anti) t and s Quark Production in CC



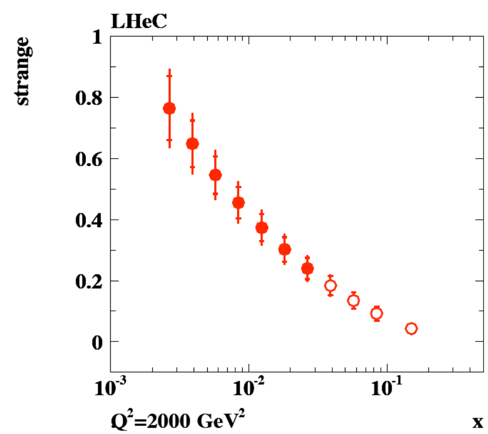
G.Brandt, MK



LHeC is a single top and single tbar quark `factory'

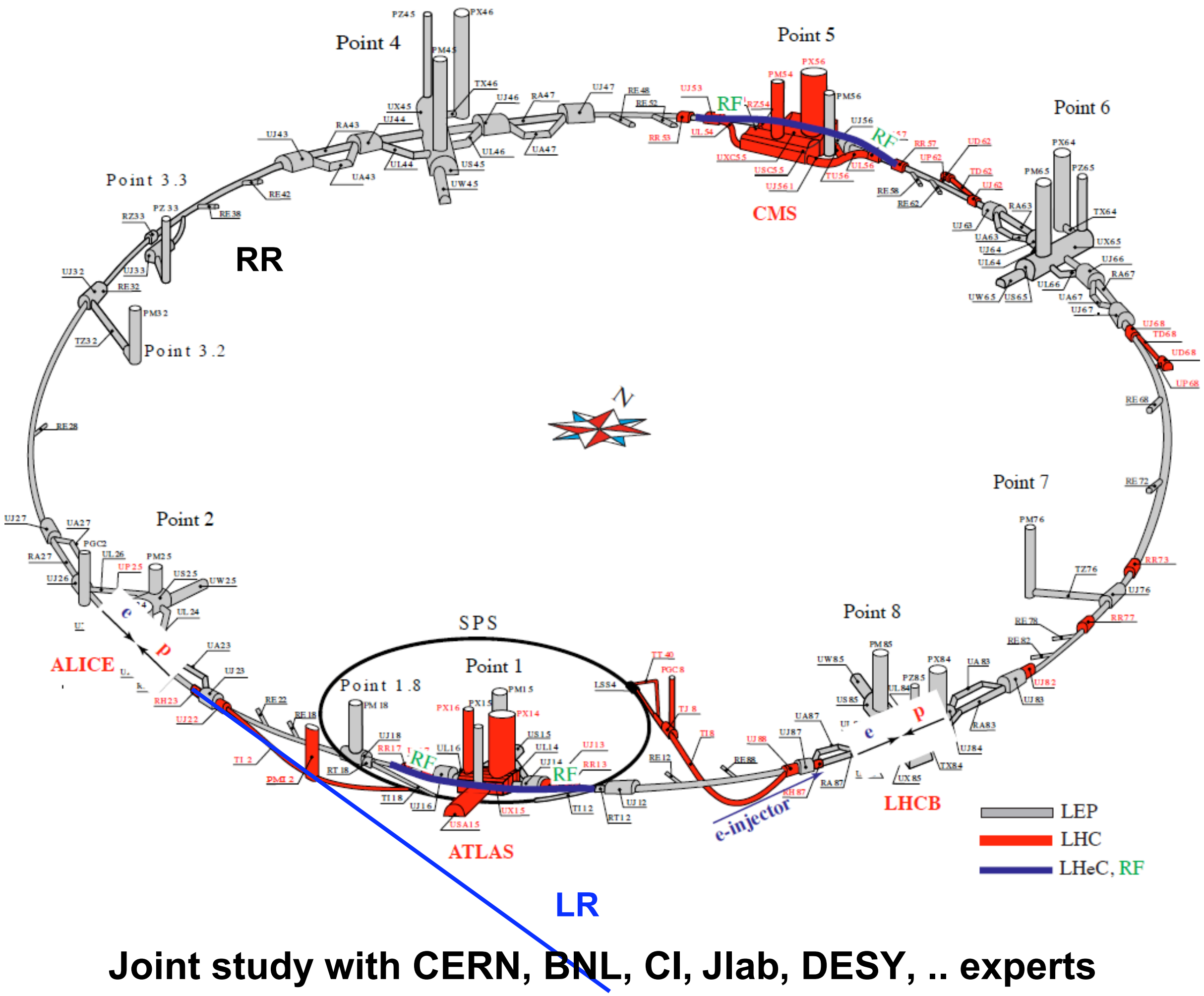
CC t cross section O(5)pb

s, sbar-df for the 1st time.



LHeC Machine

Machine Considerations



Joint study with CERN, BNL, CI, Jlab, DESY, .. experts

Max Klein LHeC ECFA 11/08

generalities

simultaneous ep and pp

power limit set to 100MW

IR at 2 or 8

p/A:

SLHC - high intensity p
(LPA/50ns or ESP/25ns)

Ions: via PS2
new source for deuterons

e Ring:

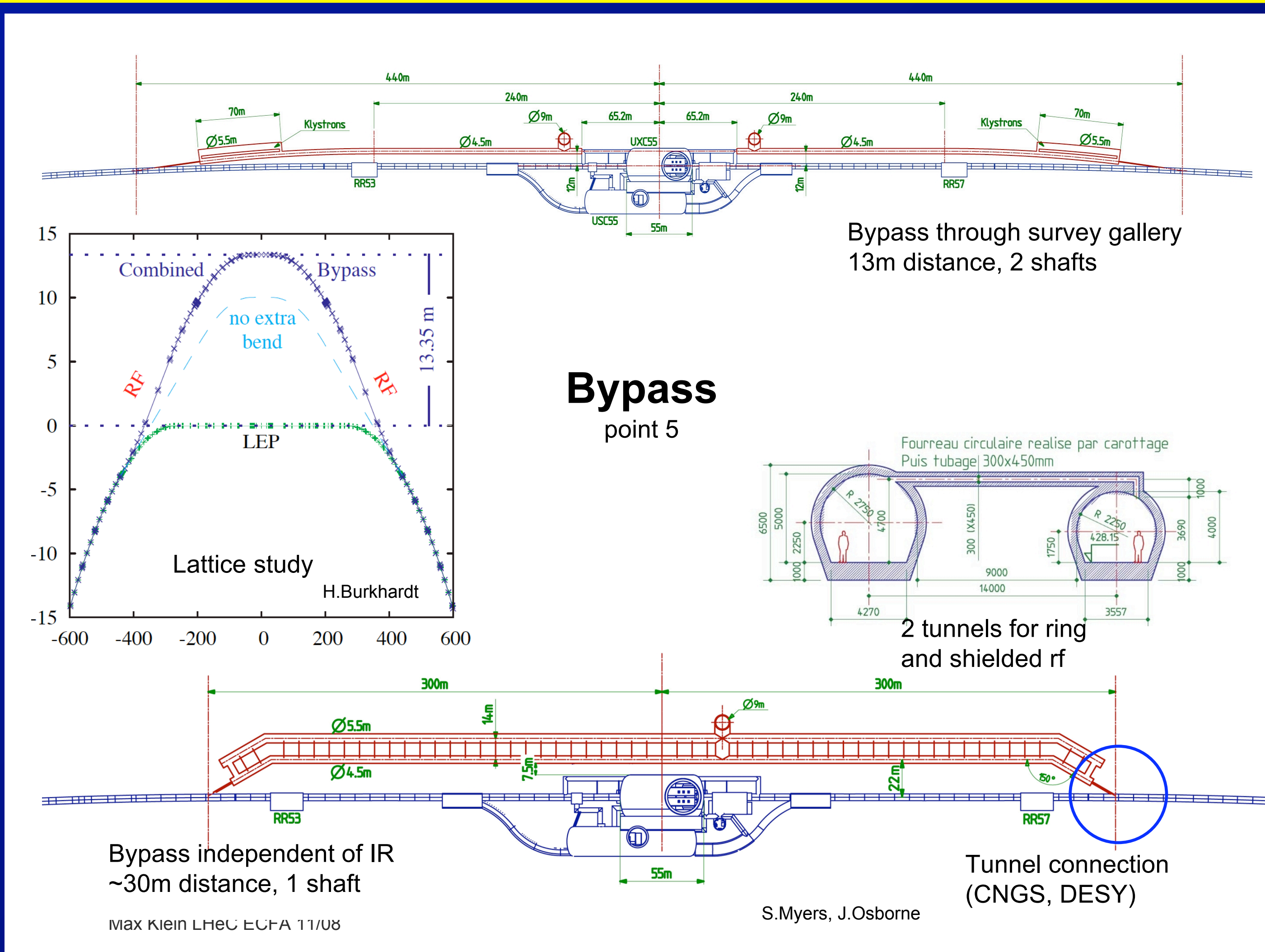
bypasses: 1 and 5
[use also for rf]

injector: SPL, or dedicated

e LINAC:

limited to ~6km (Rhone)
for IP2, longer for IP8
CLIC/ILC tunnel.?

Ring-Ring Option: Bypasses



- **Technically feasible**
  - **But implementation is challenging**

Ring-Ring Luminosity

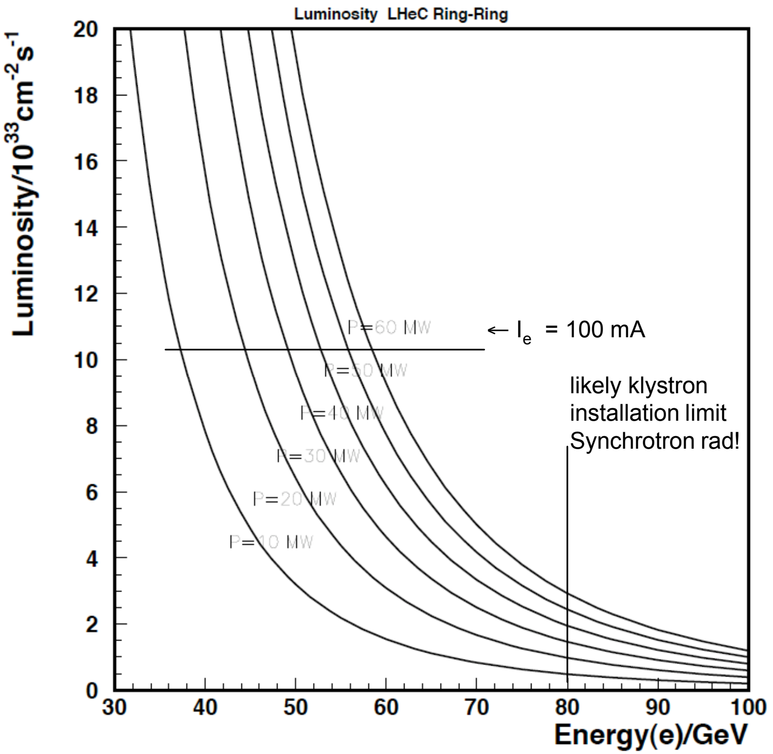
Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 2.4 \cdot 10^{33} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 5 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$

$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

10^{34}



Luminosity beyond 10^{33} in RR

HERA was 1-4 10^{31} cm^{-2} s^{-1}
Gain O(100) with SLHC p beam

Power requirement may be modest
e.g.:70 GeV with 20 MW: ~ 2 10^{33}
for the upgraded (super) p beam.

cf also A.Verdier 1990, E.Keil 1996

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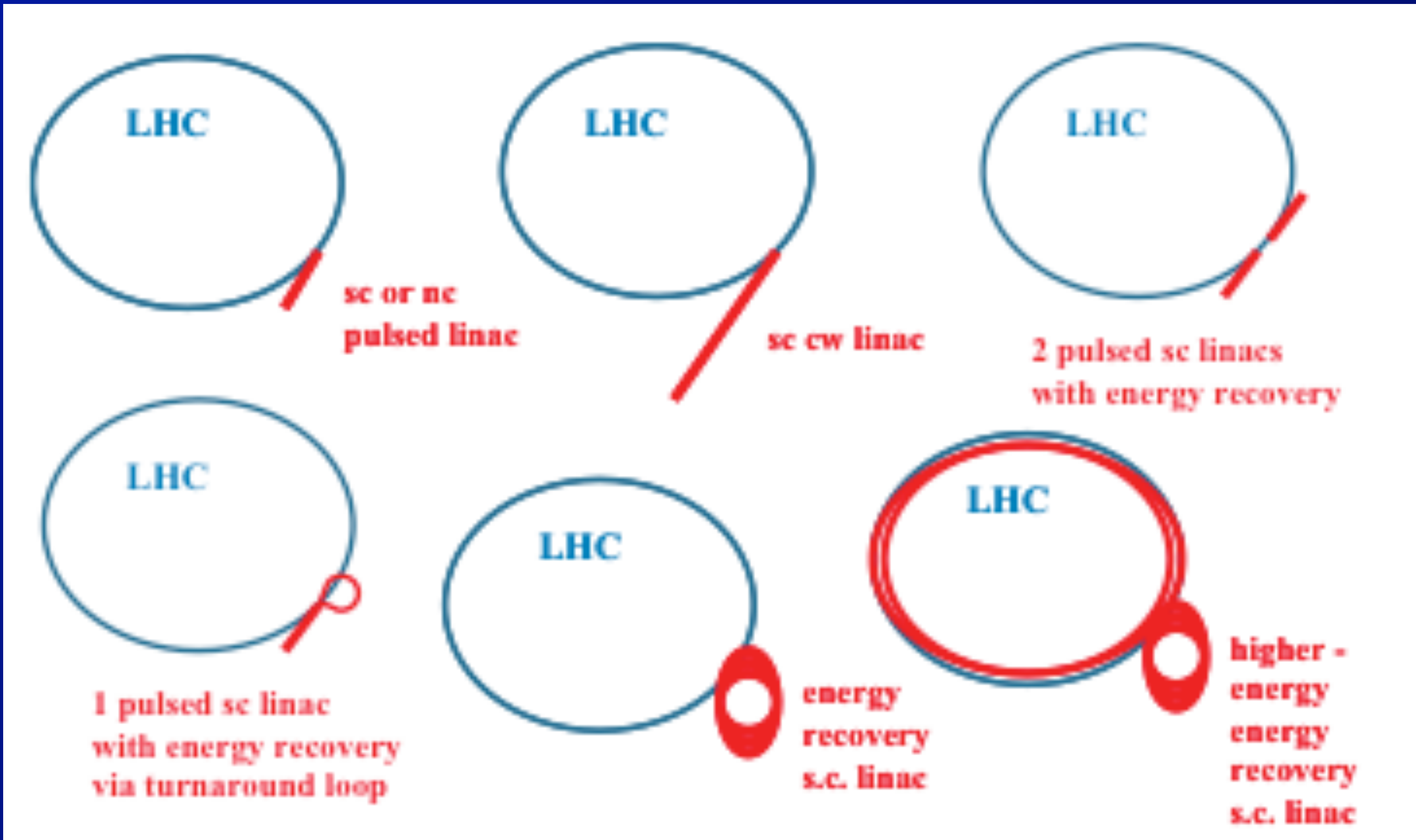
- **Difficult to reach 100 Gev with RR**

LINAC-Ring Options

- Options that were considered



Linac-Ring Comparisons

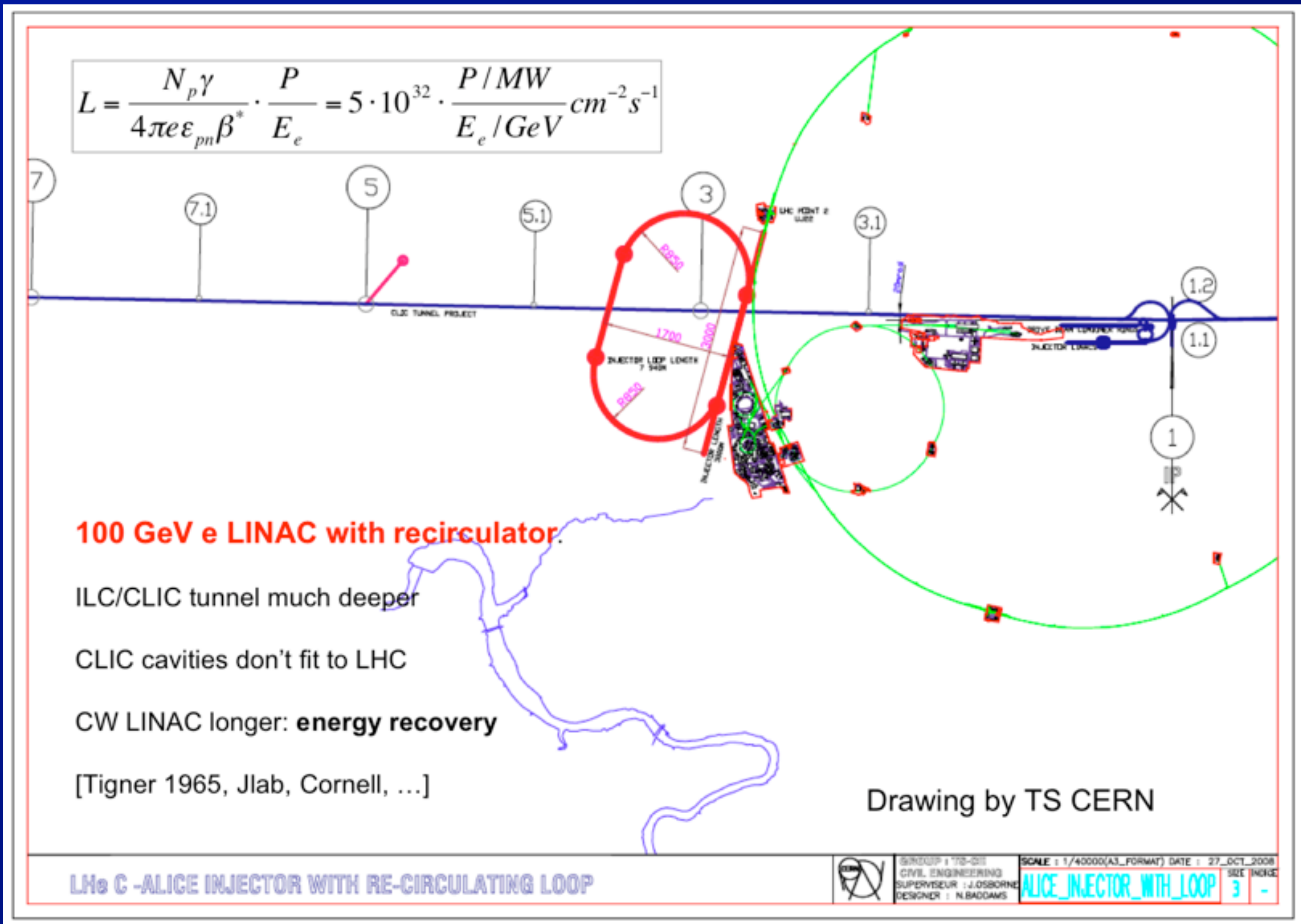
		Pulsed	CW
e- energy [GeV]	30	100	100
comment	SPL* (20)+TI2	LINAC	LINAC
#passes	4+1	2	2
wall plug power RF+Cryo [MW]	100 (1 cr.)	100 (3 cr.)	100 (35 cr.)
bunch population [10^9]	10	3.0	0.1
duty factor [%]	5	5	100
average e- current [mA]	1.6	0.5	0.3
emittance $\gamma\varepsilon$ [μm]	50	50	50
RF gradient [MV/m]	25	25	13.9
total linac length β=1 [m]	350+333	3300	6000
minimum return arc radius [m]	240 (final bends)	1100	1100
beam power at IP [MW]	24	48	30
e- IP beta function [m]	0.06	0.2	0.2
ep hourglass reduction factor	0.62	0.86	0.86
disruption parameter D	56	17	17
luminosity [10^{32} cm^{-2} s^{-1}]	**2.5**	**2.2**	**1.3**

proton parameters: LPA upgrade SLHC: N_b=5x10^{11}, 50 ns spacing, $\gamma\varepsilon$=3.75 μm, β^*=0.1 m, σ_z=11.8 cm

cf also H.Braun DIS08

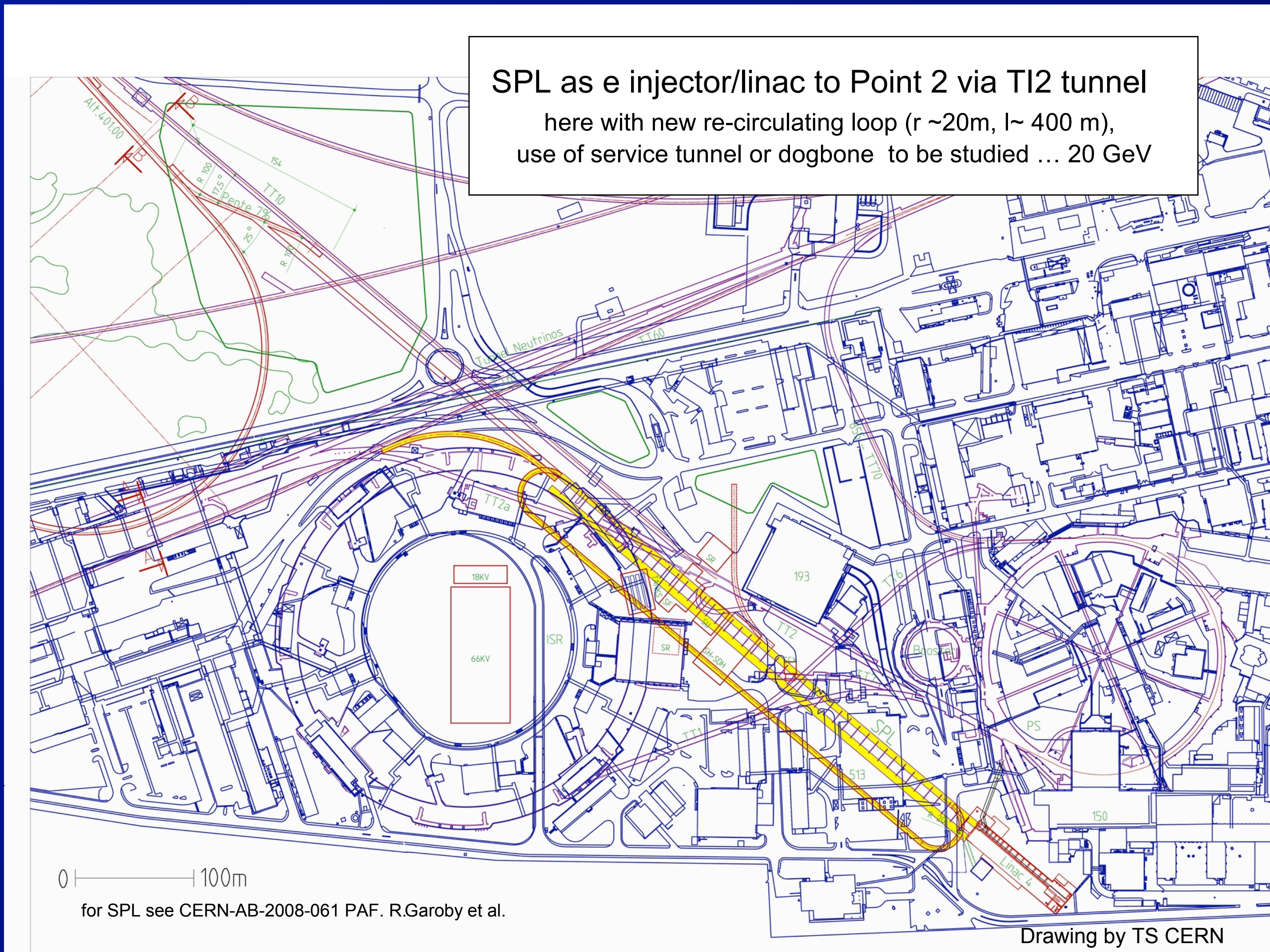
Linac-Ring Options (2)

- 100 GeV Pulsed LINAC option

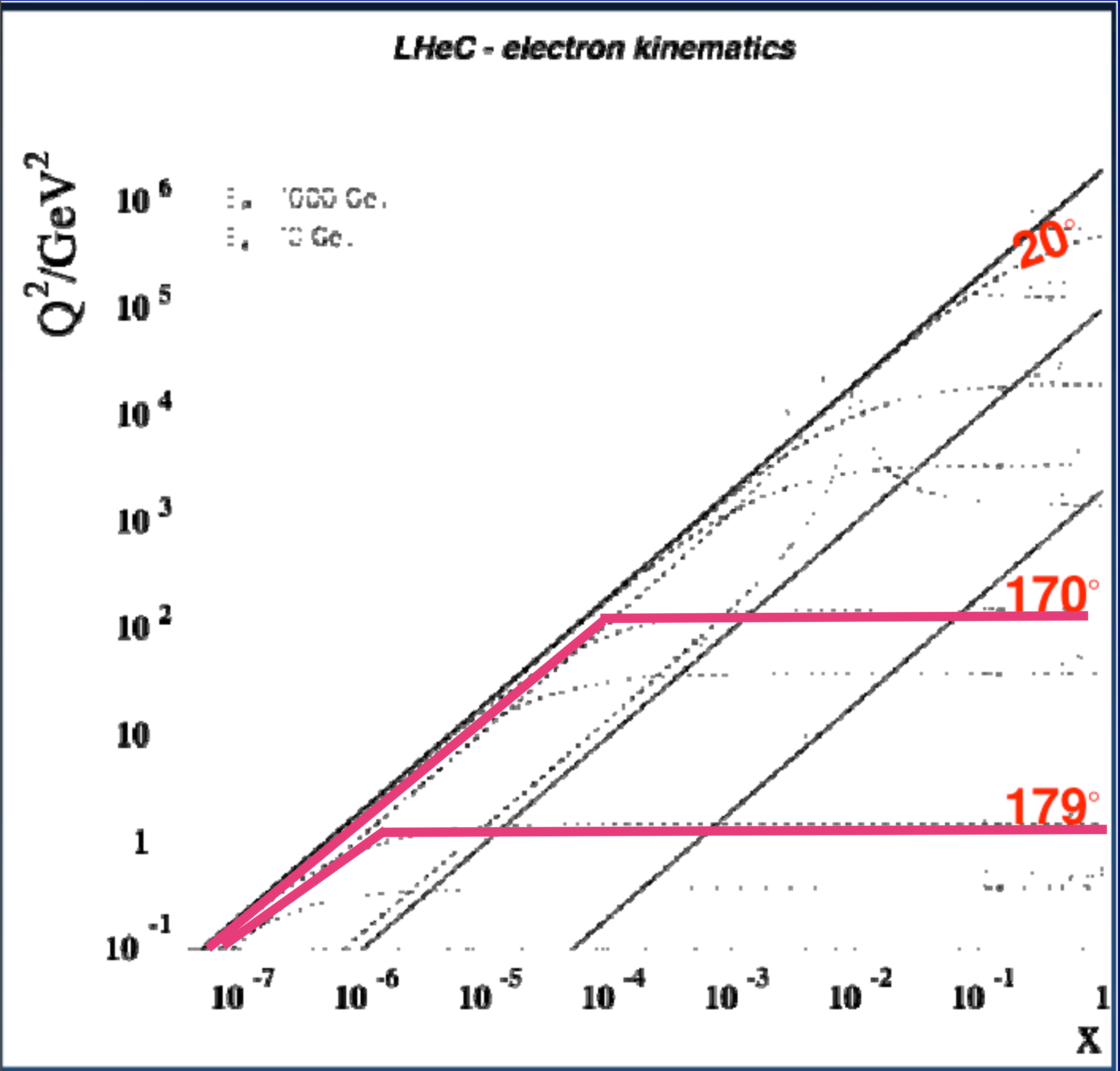


Staged LHeC

- Use SPL for 5 GeV electron beam with recirculator to reach 20 GeV



Low x, small θ acceptance



- Essential to get to small θ to take full advantage of low x @ LHeC
  - And reach $Q^2 \sim Q_s^2$
  - ideally 1°
- ~ no coverage for $Q^2 < 1$ even at 1°

Detector: low-x (down to 1°)

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)
[Return Fe not drawn]

Central Detector

Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

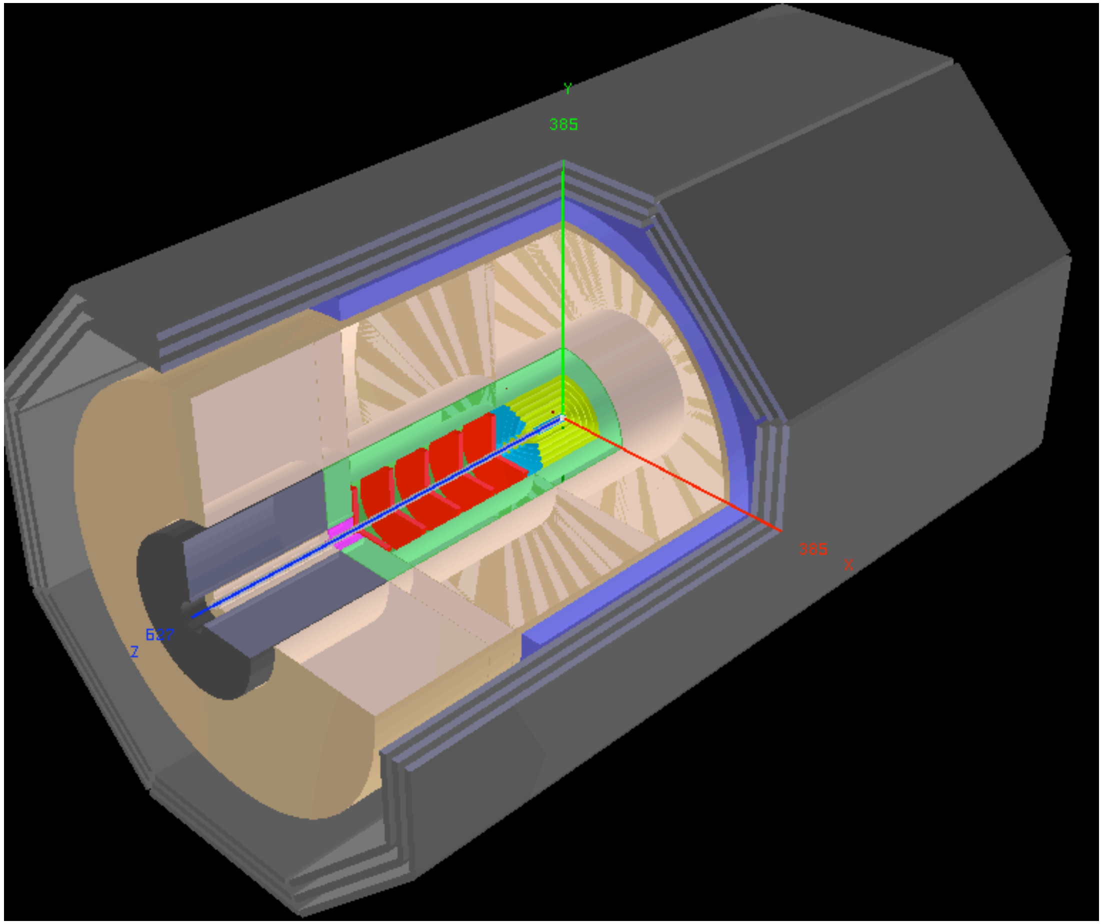
Fwd Spectrometer
(down to 1°)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

Tracker
Spacal (elm, hadr)

L1 Detector: version for low x Physics



P.Kostka, A.Pollini, R.Wallny et al

To be extended further in fwd direction. Tag p,n,d. Also e,γ (bwd)

Detector: High $\mathscr{L}$ (down to 10°)

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)

Central Detector

Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
Pixels
Elliptic pipe (~3cm)

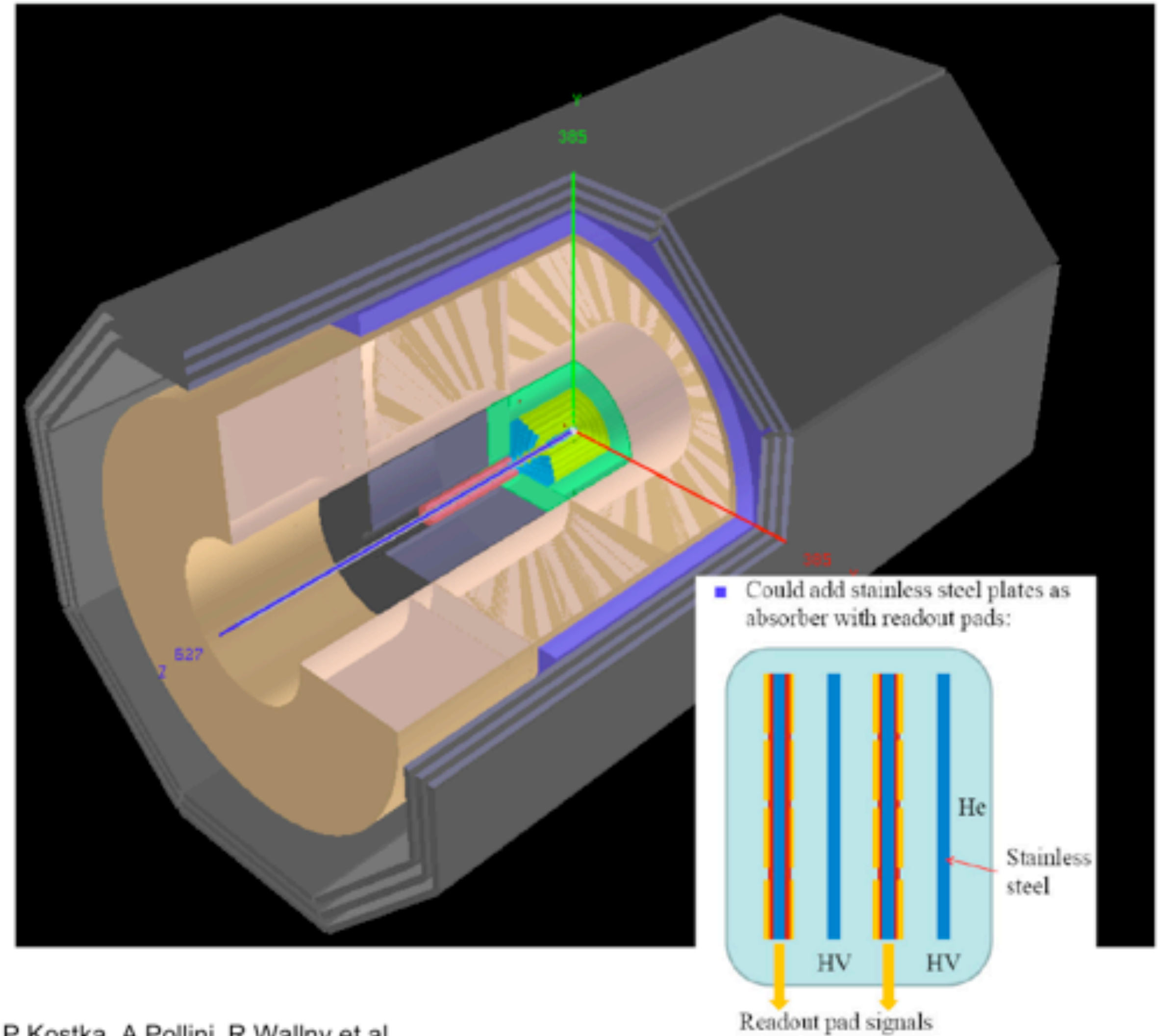
Fwd Calorimeter
(down to 10°)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170°)

Lepton low β magnets
Spacal (elm, hadr)

L1 Detector: version for hiQ^2 Physics



P.Kostka, A.Pollini, R.Wallny et al

LHeC Conceptual Design

Steps towards CDR

ECFA (11/07)

1st ECFA CERN Workshop 9/08

NuPECC (9/08), ICFA (10/08)

ECFA (11/08)

Joint workshop of convenors and steering group (12/08)

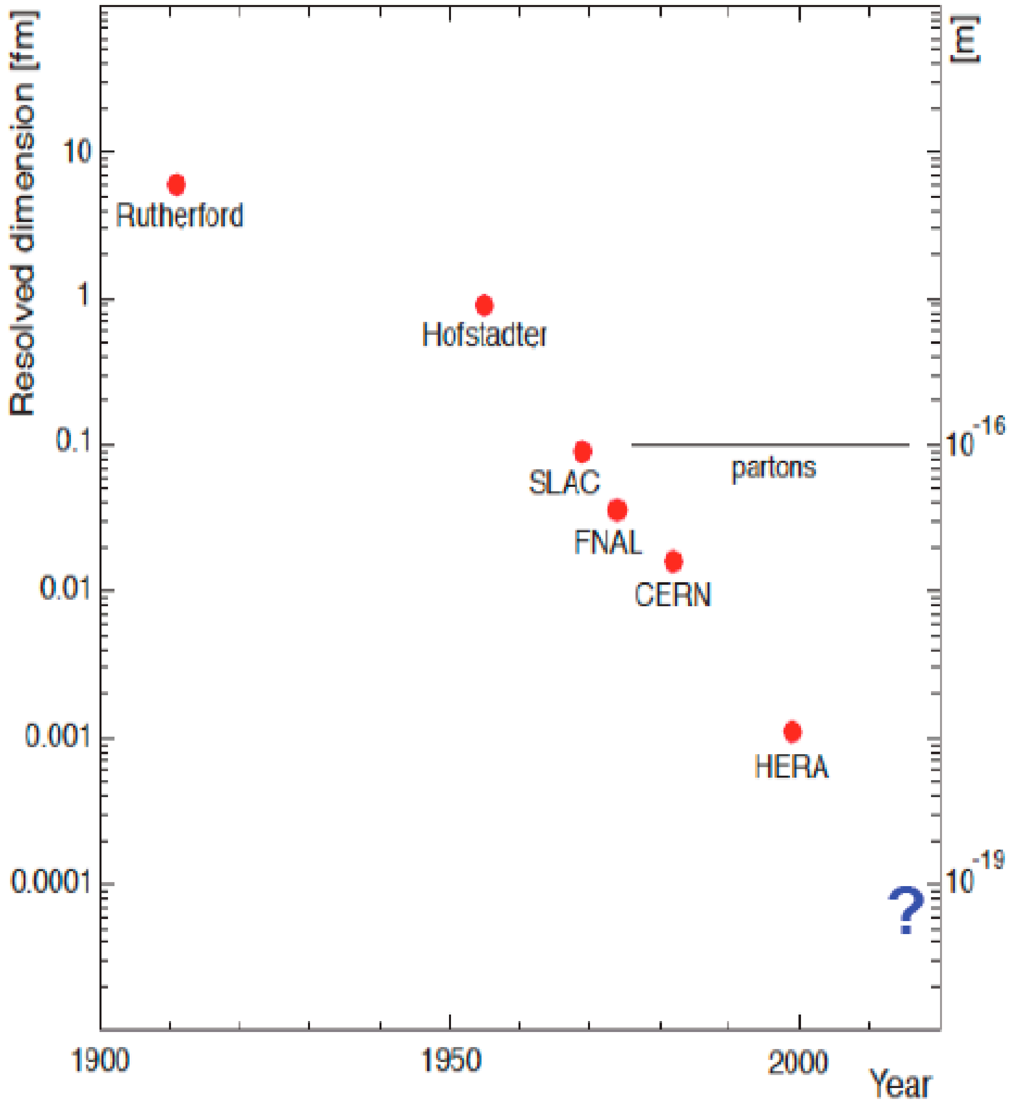
Technical Workshop (~3/09)

Physics Workshop (4/09)

2nd ECFA CERN Workshop 9/09

Final Report to ECFA 11/09

Written CDR (5/10)



LHeC Organization

Scientific Advisory Committee

Guido Altarelli (Rome)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Rolf Heuer (DESY)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg, ECFA)
Richard Milner (Bates)
Steven Myers, (CERN)
Guenter Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Towards the CDR by 2009

ECFA + CERN in 11/07 set the task to work out a CDR within 2 years on the physics, machine and detector for a TeV energy ep collider based on the LHC

DIS workshops since 05, EPAC08. ECFA-CERN: Divonne - 9/08.

Steering Group

Oliver Bruening	(CERN)
John Dainton	(Cockcroft)
Albert DeRoeck	(CERN)
Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

Joint CERN-ECFA LHeC Workshop (9/08)

- Working groups established
  - Now working on preparing CDR

First ECFA-CERN Workshop on the LHeC Divonne 1.-3.9.08

Opening: J.Ellis, Kh.Meier, G.Rosner, J.Engelen, G.Altarelli

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd
Bernhard Holzer (DESY),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design
Peter Kostka (DESY),
Rainer Wallny (UCLA),
Alessandro Polini (Bologna)

New Physics at Large Scales
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)

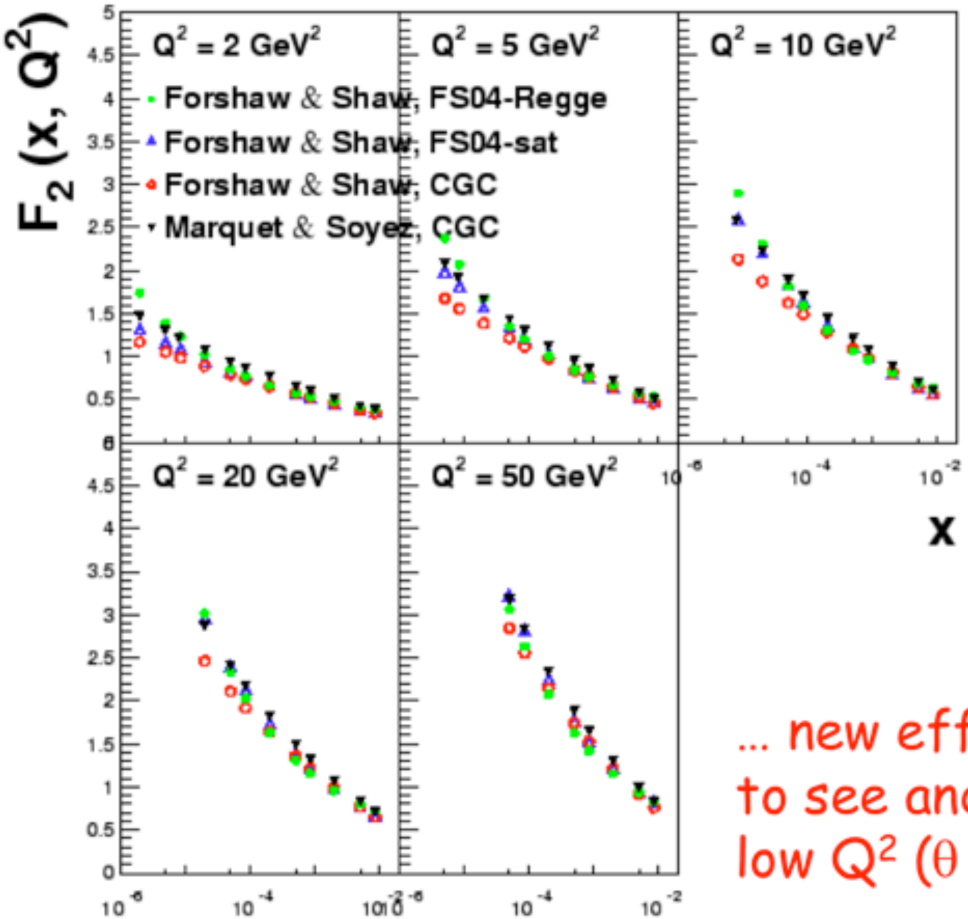
Physics at High Parton Densities
Nestor Armesto (CERN),
Brian Cole (Columbia),
Paul Newman (B'ham),
Anna Stasto (MSU)

Seeing Saturation @ LHeC

Paul Newman, Divonne LHeC workshop

Example low x F_2 with LHeC Data

With 1 fb-1 (1 year at 10^{33} cm^{-2} s^{-1}), 1° detector:
Stat. precision < 0.1%, syst, 1-3% [see Max Klein's talk]



Precise data in LHeC region, $x > \sim 10^{-6}$

- Extrapolated FS04, CGC models including sat'n suppressed at low x, Q^2 relative to non-saturating FSRegge

… new effects may not be easy to see and will certainly need low Q^2 ($\theta \rightarrow 179°$) region …

LHeC - EIC, Low-x program

- Low-x program at LHeC looks very similar to that at EIC.
  - With extended kinematic reach.
    - ⇒All the measurements we've discussed are being discussed for the LHeC
- EIC, LHeC programs complementary
  - Ideally results, experience from EIC would feed into LHeC
    - ⇒Do the time-scales work.
- LHeC low-x WG also struggling with how to unambiguously see saturation